Polarization of Terrestrial Planets and the ZIMPOL Technique

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Light reflected from planets is polarized. This basic property of planets provides the possibility for detecting and characterizing extra-solar planets using imaging polarimetry. Polarimetry is a differential imaging technique which has reached a very high sophistication. With the Zurich Imaging Polarimeter (ZIMPOL), differential aberrations, flat-fielding limitations, seeing variations or residual pointing jitter can essentially be eliminated. The ZIMPOL technique is based on a fast polarization modulator, e.g. a ferro-electric liquid crystal retarder, in combination with a special CCD camera performing the on-chip demodulation of the modulated signal. The key advantages are (1) that the two opposite polarization modes are recorded practically simultaneously (the modulation is faster than e.g. telescope jitter), and (2) that the two opposite polarization images are recorded with the same pixel so that differential aberrations or pixel gain differences are eliminated. Thanks to these properties, ZIMPOL can achieve a polarimetric precision of 0.001%. Thus a weak polarization signal from a planet can be investigated in a strong and varying background of photons. A polarimetric mode similar to ZIMPOL could be included in the coronograph concept of the TPF mission. An off-axis design produces instrument polarization which would, however, not affect the detection of a localized polarization signal. Achromatic polarization modulators may allow observations for a wide bandwidth. ZIMPOL is currently being investigated in combination with an extreme adaptive optics system for the CHEOPS project, which aims to detect, polarimetrically, extra-solar (giant) planets with the VLT. The polarization signal from terrestrial planets has significant diagnostic potential. This can be illustrated with the polarization characteristics of solar system objects. Atmosphere-free planets with surface properties like Mercury produce a scattering polarization of about 10%. The polarization p is low, about 5%, if the light is scattered predominantly from high clouds as in Venus and p is very high $> 30\%$ for thick, cloud free atmospheres as for Titan. The polarization of planet Earth depends on the cloud coverage together with the exposed areas of oceans, forests, deserts and snow fields. The contribution of each surface type is a combination of Rayleigh scattering above the surface and the reflection at the surface. The integrated effect for a pale blue dot Earth depends on the reflectance and degree of polarization of these components, which clearly depend on wavelength and scattering (or phase) angle as well as a cloud cover. The degree of polarization is particularly strong in the blue due to Rayleigh scattering in the clear atmosphere. For a pale blue dot Earth at 443 nm and 90°, scattering angle p is 23% for average cloud cover (55%), and is up to 40% for (hypothetical) 10% cloud cover. These values are calculated using polarization observations of Earth made from the Polder satellite (*Wolstencroft and Bréon*, 2004a,b). Ground-based observations of polarization indicate that "features" in the polarization may be seen in a pale blue dot Earth associated either with the vegetation red edge near 700 nm or at the rainbow angle at 140° scattering angle (water clouds). The huge variety of potential polarimetric properties of model Earth-like planets suggests that polarimetry may play an important role in the future characterization of "habitable" planets.

[a] Wolstencroft, R.D., and Bréon, F.-M., Polarization of Planet Earth and Model Earth-like Planets, *Proc. of Astronomical Polarimetry – Current Status and Future Directions*, ed. Andy Adamson, C. Aspin, C. Davis and T. Fujiyoshi, held 15-19 March 2004 in Waikoloa, Hawaii, *ASP Conference Series*, *in press* 2004.

[b] Wolstencroft, R.D., and Bréon, F.-M., Polarization of Planet Earth, Model Earth-Like Planets and Close-in Extrasolar Giant Planets, Abstract from the *Astrobiology Science Conference 2004*, held 28 March – 1 April 2004, at NASA Ames Research Center, Moffett Field, California, *Int. J. Astrobio. Supp.*, p. 34, 2004.